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THE RADIOACTIVE DENSITY METER FOR SEWAGE SLUDGE MEASUREMENT AND CONTROL

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INTRODUCTION

Automation of many sewage treatment plant processes over the past few years has resulted in more efficient operation, and in larger plants with their huge volumes of sewage has indeed become a necessity. The development of the radioactive density meter has been a significant one, for the transfer of raw sludge from primary tanks to digesters and drying processes has become a major problem. The solids content of raw sludge should be maintained at a consistent level for successful digestion and dewatering. Conventional methods of controlling the pumping of sludge have included programmed timing, electric current sensing, and visual methods, all of which have their drawbacks.

The radioactive density meter permits accurate and continuous measurement of the sludge passing through a chosen section of pipe, and additional instrumentation can provide instantaneous recording and control of the sludge being pumped. The gauge is mounted externally so that there is no contact with the sludge being measured. Although the operating principle of the density meter is simple, careful installation and calibration is essential. In addition, local conditions (such as great variety in raw sludge characteristics or greasy industrial wastes) may produce conditions that require considerably more than routine maintenance.

The first work on radioactive density meters to control sludge pumping began in the Los Angeles County Sanitation Districts in 1949; satisfactory operation began in 1959 (Garrison and Nagel, 1959). One gauge and one pump were used to control the transfer of sludge from four sedimentation tanks to digesters, with a sewage flow of 40 mgd. Blodgett (1959) reported on a similar installation at Columbus, Ohio. The benefits of precise control over sludge entering digesters were pointed out by Keefer (1960) in his description of the density meter at Baltimore, Maryland.

Radioactive density gauges to control pumping of sludge have found increasing application in North America as plants become more fully automated. They are now used in several sewage treatment plants in Ontario; Luscombe (1965) has described the installation at the Greenway plant in London, Ontario. A study carried out by the Applied Sciences Branch, Division of Research on the operations at the Little River Sewage Treatment Plant, Windsor included a check of density meter readings, and will be discussed later in this report.

DESCRIPTION OF THE METER

Radioactive density gauges are available from several manufacturers, but all are constructed on the same basic principles. A radioactive source is placed in a shielded container which is bolted onto one side of the pipe section through which the sludge flows. Cesium-137, with a half-life of 33 years, has proven to be a convenient source. Its decay is accompanied by a gamma radiation of 0.66 Mev, a relatively low energy requiring less shielding than a possible alternative such as Cobalt-60. The gamma radiation passes through the piping and sludge and is detected by a measuring cell attached to the piping opposite the source. The measuring cell, an ionization chamber, emits a small electrical signal (of the order of 10^{-9} to 10^{-13} amps) whose amplitude depends on the radiation received. The radiation absorbed by the sludge depends on the sludge density.

The electrical output from the measuring cell is amplified and indicated on a scale marked directly in percent solids or specific gravity units (s.g.u.) as desired. Recording and controlling instruments may be added to govern sludge pumping (Fig. 1). In many applications the settings are made so that the pumps operate only when the sludge density is above a specified minimum value. The range of operation of the gauges can be as low as 0.03 sgu or 10% solids, with a precision of approximately 1 - 2% of the range.

Since the radioactive source decays with time, periodic standardization is required to ensure that the initial calibration remains valid. Some sort of compensation is needed to provide a current equal in magnitude but opposite in direction to that emitted from the detector cell so that a "zero point" may be established. Most kinds of electrical zero suppression are relatively inexpensive but require frequent standardization checks on a monthly or even weekly basis. A more stable and precise method of compensation employs a compensating radioactive source which decays at the same rate as the measuring source. One manufacturer has developed a very accurate potentiometric compensation based

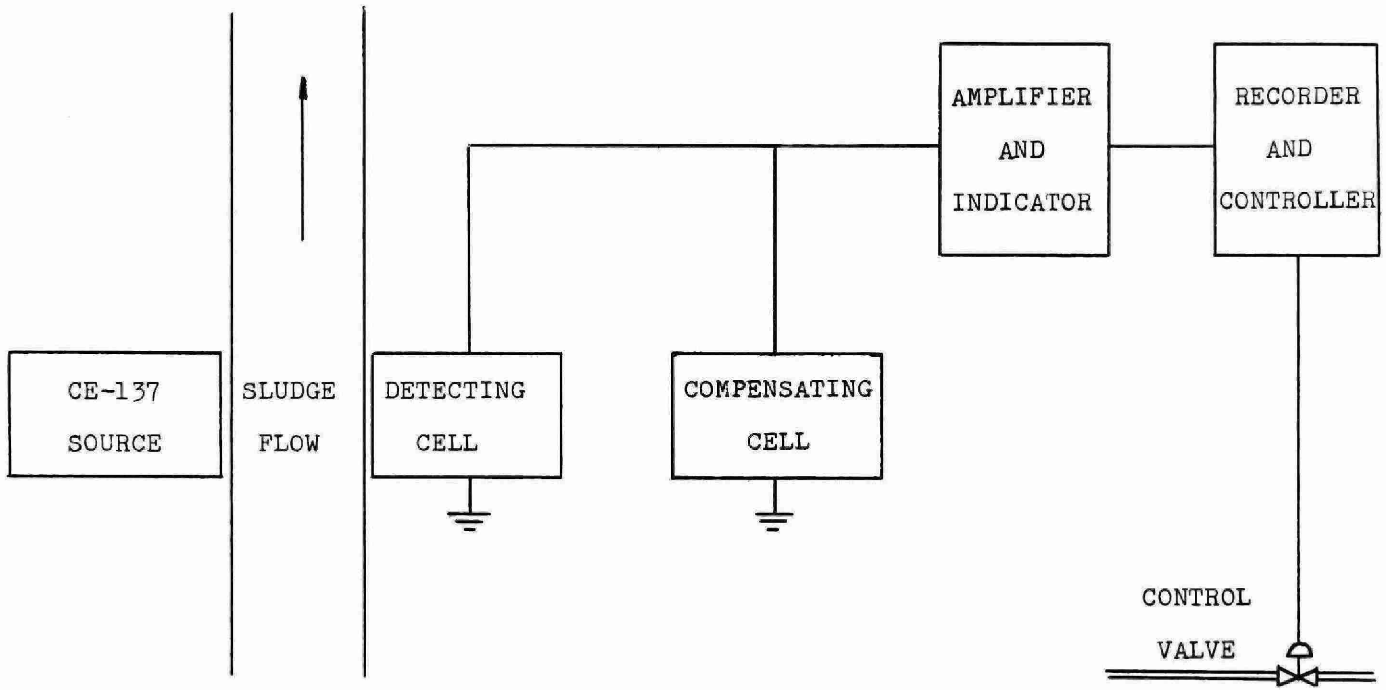


FIGURE 1 - CONTROL OF SLUDGE DENSITY USING A RADIOACTIVE SLUDGE DENSITY METER

on the decay rate of the particular Ce-137 source used, which provides for two years of continuous operation. Standardization in sewage treatment plants may be performed with fresh water or an equivalent lead absorber whose absorption characteristics fall within the range of densities being measured. Apart from the type of zero suppression employed, the frequency of standardization depends on the kind of radioactive material used as a source, the specific gravity or density range of the gauge and the radiation path length through the sludge.

The response times of the gauges can range from one second to several minutes. With shorter time constants the cost of the gauge increases and the accuracy decreases, especially for time constants less than 15 seconds, so that plant needs should be carefully evaluated before choosing a gauge. With small time constants errors may be introduced because of the sporadic nature of gamma radiation from the source.

The source is well shielded to prevent harmful exposure to operators from radiation. Applications for a Radioisotope Licence must be made to the Atomic Energy Control Board, Ottawa for each installation. Leak tests should be carried out on the gauges at six month intervals.

INSTALLATION, CALIBRATION AND OPERATION

a) Meter Configurations

There are several ways to mount a radioactive source and detector on a pipe section, the configuration used in any particular case depending on the accuracy required and fluid characteristics (Cook, 1965a). Sewage sludges are often measured with the gauge simply mounted on a section of the process piping. As long as the thickness of the absorber (i.e. the internal diameter of the pipe) is sufficient to provide a measurable change in the radiation intensity at the detector cell, this mounting is adequate.

When the pipe size is too small, or increased accuracy is required, the meter may be fixed onto expanded sections of the pipe, of either round or rectangular shape. The round expansion is not suited to viscous fluids as "tunnelling" may occur, and solids may settle out in the expanded section. A rectangular expanded section is more suitable for sewage sludge as there is less likelihood of settling out and the turbulence produced helps to scrub the pipe walls and prevent grease buildup. For narrow lines less than four inches in diameter, increased accuracy and sensitivity may be attained by using an axial mounting on a Z-shaped pipe section.

In general it is recommended that the gauge be attached to a vertical pipe section. If only a horizontal section is available, the density meter should be mounted vertically so that any heavy solids that move along the bottom of the pipe are included in the measurements. It is essential that the pipe be completely filled with sludge during measurement, as the inclusion of air or other gases will lead to faulty readings. Whatever configuration is chosen, the installation should be practical so that cleaning of the pipe sections and fresh water circulation for standardization are facilitated.

b) Calibration

The zero point of the radioactive density gauge is obtained by passing fresh water through the piping at the same temperature as the sludge to be processed. The compensating radioactive cell or electrical power source are adjusted to obtain this point on the indicator. The calibration of the instrument for the operating range of 0 - 10% or 0 - 15% solids generally requires considerable sampling and checking. A range of 0 - 10% solids corresponds roughly to a specific gravity range of 1.0 - 1.03 sgu, but the actual relationship depends on the specific gravity of the solids in the sludge being handled and should therefore be determined for each plant.

There are many difficulties inherent in comparing gauge readings with the results of physical sampling, since sampling procedures themselves may be suspect. As Cook (1965b) points out, even when the manual sample measurement would be expected to be considerably more accurate than the meter reading, human error in obtaining and analyzing the sample can make comparisons meaningless. Sampling points should be representative and comparable with meter readings. For example, samples taken from near the wall of the pipe rather than the centre may not be representative. There may be a time lag between the sampling point and the gauge, particularly with heavy sludges.

Once sampling procedures have been determined as being accurate, tests may be made to determine the relationship between the specific gravity and the percent solids in the sludge.

c) Maintenance and Operation

Routine electrical and mechanical maintenance should normally present few problems. Restandardization of the radioactive density gauge due to decay of the Cesium-137 source must be carried out periodically. As mentioned above, meters using electrical zero suppression normally require more frequent restandardization, with weekly or monthly checks advisable.

Operational difficulties may vary widely from plant to plant depending on the consistency and type of raw sludge, seasonal temperature changes, the amount of grease buildup in the lines and generation of gas in the sludge. Sewage treatment plants that are subjected to occasional shock loadings of industrial wastes, for example, will find errors in the meter readings in these periods. Any change in the specific gravity of the solids (or the transporting fluid) being measured will affect the accuracy of the gauge readings since the specific gravity - percent solids relationship is determined for normal sewage flows. These variations also make selection of a percent solids cut-off point difficult.

Industrial wastes may cause grease buildups on the pipe walls. Coatings of grease cause high density gauge readings, while fatty buildups of lower density than the sludge result in lower indicated densities. These buildups may be removed with steam or chemical solvents, but can become a great nuisance in some plants.

Since the density of water, and therefore sludge, changes with temperature, large seasonal temperature variations may affect the gauge readings. No automatic temperature compensation is required as these variations are long-term, and changes in sludge temperature may be compensated for by standardizing the instrument using water at the sludge temperature.

Gas generation can cause faulty gauge readings. Air may be introduced into the process piping through leaky valves and seals, so maintenance of the piping is essential. Bacterial action in the sewage sludge may also produce gases whose effect on the indicated sludge density will depend on such factors as the gauge configuration, gauge location with respect to the pump and any restrictions in the piping, and the pump speed.

APPLICATIONS

The importance of controlling the thickness of sludge pumped to digesters can be realized both from an economic and practical point of view. Costs may be lowered both by eliminating sludge thickeners and improving digester capacities. By monitoring the sludge density, the quantity of sludge pumped is reduced and savings in pump capacity and power needs may be made. Dewatering of sludge after or as an alternative to digestion is more efficient if a consistent thickness can be maintained.

Normal methods of controlling sludge pumping are only partially satisfactory. Visual estimates of sludge density rely on the operators' ability to determine the percent solids in the sludge. Continuous samplings and analyses may provide better results, but these take time and do not provide immediate pump control. Programmed timers are common in larger treatment plants. These are satisfactory if the rate of sludge accumulation in the primary tanks is constant and if the pumps are able to deliver a constant flow under all head conditions. An electric current sensing technique has been used with centrifugal pumps, whose power requirements vary with the flow. Electric current sensing is not always dependable because fluctuations in current flow can be caused by factors other than changes in solids concentration.

The radioactive sludge density meter not only provides instantaneous indications of sludge density, but when combined with the recording and controlling devices mentioned earlier gives complete and continuous control over pumping operations. With complete automation of the process much time may be saved by operating personnel. It should be noted that trouble-free pumps are essential to control systems governed by a radioactive density meter. Non-clogging pumps of a torque-flow or positive displacement type are best suited to thickened-sludge flows.

The nature of the monitoring system used to control the pumping of sludge depends on the source and type of sludge, the size of the plant and degree of automation, the number of primary sedimentation tanks and digesters and the dewatering methods to be employed. The operation at the Little River plant, Windsor, is relatively simple since sludge is pumped directly from one of two primary tanks to a chemical conditioning tank and vacuum filter. In larger plants, such as those operated by the Los Angeles County Sanitation Districts, control systems may be much more complicated (Compton, 1959; Garrison and Nagel, 1959). Many plants employ elaborate systems of timers and switches to control pumping from several primary tanks to digesters or holding tanks prior to mechanical dewatering. A predetermined cut-off point ensures that only sludge of a desired thickness is transferred.

In many cases it is useful to determine the mass flow. A magnetic flow meter may then be used in conjunction with the radioactive density gauge to determine the number of pounds of dry solids pumped. The use of the gauge need not be limited to transfer from primary tanks. Blodgett (1959) reported that the first application of the meter at Columbus, Ohio was made on the activated sludge return lines from the final settling tanks to the aeration tanks. The solids content of digested sludge should be determined accurately if it is to be dried and sold as a soil conditioner or fertilizer base. Drying beds might be operated more efficiently by controlling the thickness of digested sludge applied to the beds.

MEASUREMENTS AT THE LITTLE RIVER SEWAGE TREATMENT PLANT, WINDSOR

The Little River plant provides secondary treatment using the activated sludge process. It was designed for a dry-weather flow of 4 mgd, but has been operating at well below this capacity. A novel feature of the plant is the design of the primary settling tanks, in which sludge is raked towards the center of the tanks and stored in central drop sections, from which it is pumped at intervals to a vacuum filter. This construction permits sludge to accumulate and thicken without having to build tanks specifically for that purpose. A portion of the activated sludge from the final settling tanks is returned to the primaries and settles with the raw sludge.

The combined raw and waste activated sludges are withdrawn from the primary tanks by two plunger-type pumps through 4" diameter glass-lined cast-iron piping to a conditioning tank and coil-spring vacuum filter. A radioactive density gauge is mounted on a vertical section of this pipe below the conditioning tank. Sludge is normally withdrawn from the primaries for filtration for about ten hours a day, but sometimes the primaries are by-passed in order to permit a buildup of the sludge blanket in the tanks. Sludge withdrawn from the primary tanks might contain 8 - 10% solids on the average, but periods of higher or lower solids concentrations occur at times.

The density meter is used primarily as a means of recording the percent solids of the sludge, since the sludge is normally thick enough for continuous filtration. Most of the raw sewage is of residential origin, so that the sludge is of a reasonably consistent type. The density gauge also helps to provide an estimate of the amount of coagulants added prior to filtration. It should be noted that chlorine is sometimes injected into the sludge line at a point below the density meter. Since the chlorine is injected with water (at rates up to 7 gpm) a dilution of the main sludge stream of 1 - 2% solids results. The chlorine reduces odours and appears to aid coagulation.

As part of a more comprehensive study at the Little River plant in late May and early June, 1967 members of the Applied Sciences Branch took several sludge samples in order to check the meter readings. A total of 36 samples were obtained from May 29 to June 1, and again on June 13. Sludge samples were obtained from two points on the line. An "undiluted" sample was taken before the point of chlorine injection and a "diluted" sample immediately below the density gauge. Corresponding readings of the density meter were taken, allowing for a 20 minute lag in the case of the "undiluted" samples. The measured dry weight (expressed as percent solids) of the samples as determined in the laboratory is compared with the meter readings in Table 1.

The samples obtained on June 13 are the best for direct comparison with the meter readings since no chlorine was injected that day. The mean percent solids of 12 samples was 0.90% higher than the meter indications. From May 29 to June 1, 13 samples of sludge diluted after chlorine injection showed a 0.46% higher mean. Samples of sludge taken prior to chlorine injection showed a 1.45% higher mean than the meter, indicating that the sludge was diluted by about 1% solids at this thickness.

Although the number of samples obtained was small, the density meter indicated consistently lower densities than the laboratory analyses. The meter had not been standardized for several weeks prior to these measurements, but decay of the source would cause meter readings to drift upwards rather than downwards. A more likely explanation of the differences on June 13 is that following heavy rains prior to June 13 (with subsequent high flows and densities) the character of the sludge solids differed from those of the normal domestic flows. The consistency of the differences supports this idea.

The results of Table 1 are presented graphically in Figure 2, only the "diluted" samples being included from May 29 to June 1. The pattern depicted on June 13 was typical of the chart recordings of a day's operation at the plant,

TABLE 1

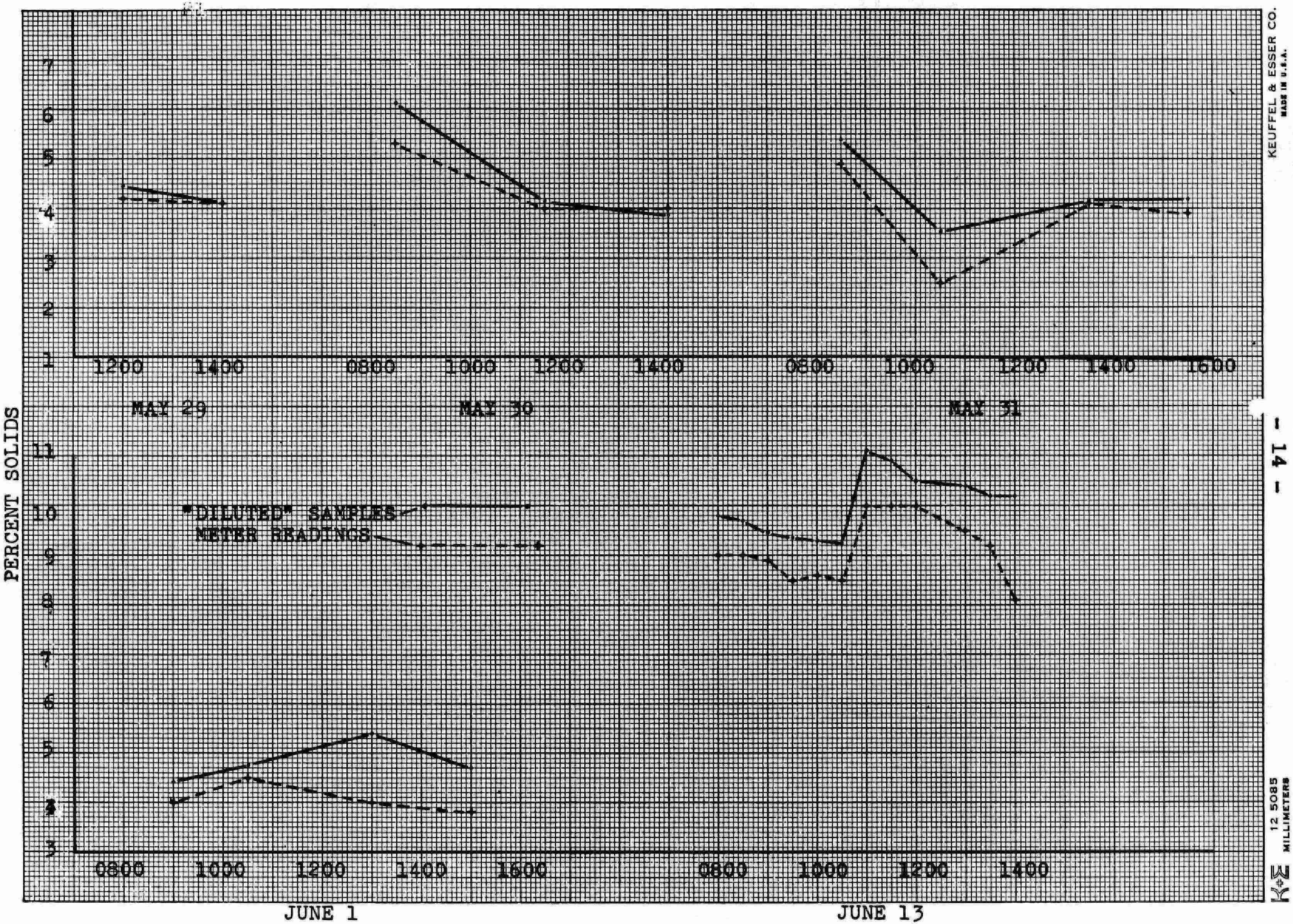
COMPARISON OF METER READINGS WITH LABORATORY SAMPLES

Date 1967	Time	Measured Dry Weight (% Solids)		Meter Reading (% Solids)	Differences in % Solids
May 29	1200	4.46	diluted	4.2	0.26
	1300	3.25		3.5	-0.25
	1400	4.11	diluted	4.1	0.01
	1500	5.31		4.4	0.91
May 30	0830	6.11	diluted	5.3	0.81
	1030	5.95		5.3	0.65
	1130	4.15	diluted	4.0	0.15
	1300	6.00		3.7	2.3
	1400	3.88	diluted	4.0	-0.12
	1500	5.08		3.8	1.28
May 31	0830	5.4	diluted	4.9	0.5
	0930	5.32		3.8	1.52
	1030	3.52	diluted	2.5	1.02
	1130	5.86		3.9	1.96
	1330	4.19	diluted	4.1	0.09
	1430	5.97		3.9	2.07
	1530	4.2	diluted	3.9	0.3
June 1	0900	4.41	diluted	4.0	0.41
	0930	7.7		4.7	3.0
	1030	4.73	diluted	4.5	0.23
	1130	5.56		4.1	1.46
	1300	5.4	diluted	4.0	1.4
	1400	5.36		4.3	1.06
	1500	4.7	diluted	3.8	0.9
June 13	0800	9.8	#1 tank	9.0	0.8
	0830	9.7	#1 tank	9.0	0.7
	0900	9.45	#1 tank	8.9	0.55
	0930	9.35	#1 tank	8.5	0.85
	1000	9.3	#1 tank	8.6	0.7
	1030	9.25	#1 tank	8.5	0.75
	1100	11.1	#2 tank	10.0	1.1
	1130	10.9	#2 tank	10.0	0.9
	1200	10.5	#2 tank	10.0	0.5
	1300	10.4	#2 tank	9.5	0.9
	1330	10.2	#2 tank	9.2	1.0
	1400	10.2	#2 tank	8.1	2.1

Mean Values

13 Diluted Samples (May 29 - June 1)	Difference 0.46%
11 Undiluted Samples (May 29 - June 1)	Difference 1.45%
12 Samples (June 13)	Difference 0.90%

FIGURE 2 - COMPARISON OF METER READINGS WITH "DILUTED" SAMPLES



except that normally sludge is filtered for about ten hours a day. Sludge from primary tank #1 was pumped to the filter with a gradual drop in percent solids until late morning when sludge withdrawal was switched to primary #2. For the periods studied at Windsor, it may be concluded that the meter was reading low by 0.5 - 1% solids, but that the injection of chlorine and high flows following rain may have produced atypical conditions.

SUMMARY

1. Radioactive sludge density gauges can provide accurate, continuous and instantaneous indications of sludge density.

2. Used in conjuction with control devices, the gauges can provide complete control over sludge pumping in a plant.

3. Digestion and dewatering should become more efficient and less costly.

4. Careful installation, calibration and operation are essential.

5. Some plants may experience considerable difficulties because of local sludge characteristics.

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